ACCURATE REAL-TIME OBJECT TRACKING WITH LINEAR PREDICTION METHOD

P.Y. Yeoh and S.A.R. Abu-Bakar
Dept. of Microelectronics and Computer Engineering
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
81310 Skudai, Johor, Malaysia.
yeohpy@hotmail.com and syed@suria.fke.utm.my

ABSTRACT

This paper presents an efficient technique for real-time tracking of a single moving object in terrestrial scenes using a stationary camera. The tracking algorithm is based on the Linear Prediction (LP) solved by the Maximum Entropy Method (MEM). It attempts to predict the centroid of the moving object in the next frame, based on several past centroid measurements. Using a second order of the Linear Prediction method, the proposed algorithm is able to accurately track the moving object. It has been shown analytically that the proposed recursive predictor-corrector tracking algorithm is able to yield high accuracy performance and is superior to that of the Kalman Filter, for a possibly random movement of single moving object.

1. INTRODUCTION

In general, the existing approaches formulated to deal with tracking of a single moving object or multiple objects can be classified into a few categories, i.e. feature-based approach, template-based method, gradient-based method, statistical model and prediction approach. The feature-based and template-based methods are less robust to changing shape of the tracked target and temporary occlusions, whereas the statistical models are quite computationally demanding in most cases.

The proposed tracking algorithm is focused on the prediction approach, which enables faster tracking speed to be achieved. The existing prediction techniques are mainly based on Kalman Filter (KF) and Extended Kalman Filter (EKF) [1,2,3]. However, they are less robust to varying orientations of motion and can be error-prone if the tracked target changes its direction.

With the motivation of achieving real-time speed as well as improving the existing tracking speed and accuracy, Linear Prediction has been integrated with the Projection Histograms technique in the proposed tracking algorithm. Although the Linear Prediction method is not new, its efficiency and potential applicability in vision-based predictive object tracking system has not been explored.

This proposed algorithm enables accurate and robust tracking of a wide variety of objects, without constraining the system to know the a priori characteristics (shape and size) of the object. Another significant advantage by incorporating the Linear Prediction method is that it gives better performance in accuracy compared to that of the Kalman Filter.

The structure of this paper is as follows: Section 2 presents the motion detection process. Section 3 discusses the proposed tracking approach, these include discussions on Projection Histograms technique, the Linear Prediction and Maximum Entropy Method. Section 4 illustrates the performance of the proposed algorithm and finally conclusions are drawn in Section 5.

2. MOTION DETECTION

The input live video image is directed to the motion detection module, where the Hexagonal Edge Detector proposed in [4] is applied.

The motion detection scheme employs the frame differencing technique for extracting edges of moving object from the static-background image sequences. In this stage, differencing of moving edges at all spatial locations of the image are binarized based on a threshold value, to distinguish between the possibility of motion from the static background. The resulting edge map output contains information about the location, size as well as the shape of the moving object.

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The entire moving edges extraction process is shown in Figure 1.

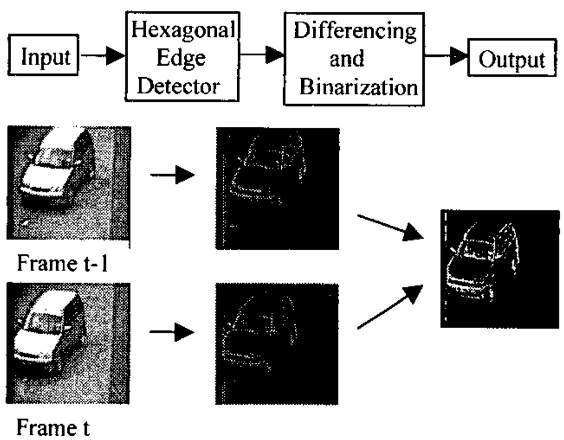

Figure 1: Moving edges extraction process.

3. MOTION TRACKING

The proposed tracking algorithm integrates the Projection Histograms technique and the Linear Prediction technique in order to achieve real-time tracking performance.

3.1. Projection Histograms

The employed Projection Histograms technique is applied to the output edge map to determine the actual location (centroid) of the moving object in the current frame. This technique is similar to the one adopted in [5].

The projection values are obtained from the binarized output. Projection of the horizontal axis, $P_h(i)$, is obtained by summing up all the pixels column-wise, while projection of the vertical axis, $P_v(j)$, is obtained by adding all the pixels row-wise.

From these projection values, a rectangle that encompasses the moving object will be formed (as shown in Figure 2). Then, the centroid of the object can be calculated as follows:

x coordinate of the centroid, C_x = (Hs + He) / 2

y coordinate of the centroid, C_y = (Vs + Ve) / 2

where:

Hs = x coordinate at the beginning of the horizontal perimeter

He = x coordinate at the end of the horizontal perimeter

Vs = y coordinate at the beginning of the vertical perimeter

Ve = y coordinate at the end of the vertical perimeter

Each centroid location is stored in the prediction database. Once a sufficient number of data is available (corresponds to the order of Linear Prediction used), prediction for the centroid in the next frame is executed. Each prediction of $\hat{C}_x$ and $\hat{C}_y$ is performed independently and the corresponding prediction values are stored in the separate prediction database.

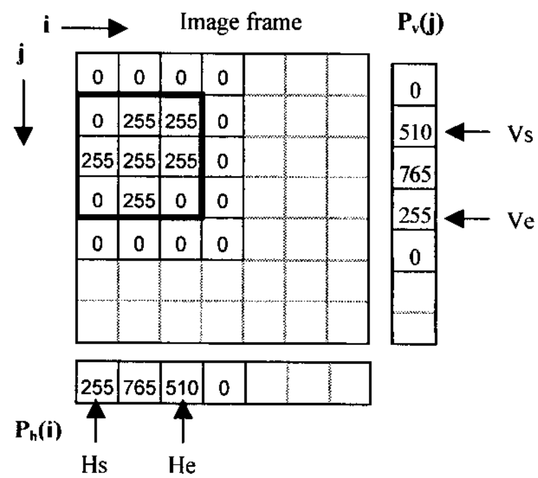

Figure 2: Summations of rows and columns to obtain vertical and horizontal projections.

The centroid error, C_e, is defined as the Euclidean distance between the actual centroid and the predicted centroid, as follows:

$$C_e = \sqrt{(C_x - \hat{C}_x)^2 + (C_y - \hat{C}_y)^2}$$

If the error exceeds the pre-fixed threshold value, then the centroid value in the prediction database will be updated with the actual value. Otherwise, the location of the moving object for the next time interval will be determined solely by the predicted centroid value. These prediction-correction steps will be performed recursively.

3.2. The Linear Prediction Method

The Linear Prediction (LP) method is integrated in the proposed tracking algorithm to determine the prediction value of the next centroid location (denoted as $\hat{C}_n$), based on the target's finite past centroid measurements, namely $\{ C_{n-i}$; i = 1,2,...,$p\}$. The best linear predictor of order p can be defined as shown in (1):

$$\hat{C}_n = -\sum_{i=1}^{p} a_i C_{n-i} = -[a_1 C_{n-1} + a_2 C_{n-2} + .. + a_p C_{n-p}] \quad (1)$$

The p prediction coefficients a_1, a_2, ..., a_p are chosen to minimize the mean-squared prediction error, i.e.

$$\varepsilon = E[e_n^2] = \min \quad (2)$$

where e_n is the prediction error:

$$e_n = C_n - \hat{C}_n = C_n + a_1 C_{n-1} + a_2 C_{n-2} + ... + a_p C_{n-p} \quad (3)$$

and C_n is the actual centroid obtained by the Projection Histograms technique.

Based on the Orthogonal Projection Theorem and the minimization criterion in (2), $(p+1)$ x $(p+1)$ matrix equations as shown in (4) are obtained, where R(k) is the autocorrelation function for the series of centroid values, C_n.

$$\begin{bmatrix} R(0) & R(1) & R(2) & \cdots & R(p) \\ R(1) & R(0) & R(1) & \cdots & R(p-1) \\ R(2) & R(1) & R(0) & \cdots & R(p-2) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ R(p) & R(p-1) & R(p-2) & \cdots & R(0) \end{bmatrix} \begin{bmatrix} 1 \\ a_1 \\ a_2 \\ \vdots \\ a_p \end{bmatrix} = \begin{bmatrix} \sigma_e^2 \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (4)$$

The best linear predictor of order p for the centroid, $\hat{C}_n$ can be obtained by solving the resulting matrix equations shown in (4). Since the matrix has a Toeplitz structure, the solutions (prediction coefficients $a_1, a_2, ..., a_p$) can be obtained efficiently by using Maximum Entropy Method.

This method is employed in the proposed algorithm as it is capable to ensure that the predictor does not run off the block of data, and always results in a minimal-phase filter. Moreover, its minimization criterion is able to produce more precise prediction (compared to the autocorrelation and covariance method), by minimizing the sum-squared of both the forward and backward prediction errors, i.e.:

$$\varepsilon = \sum_{n=p}^{N-1} [e_p^+(n)^2 + e_p^-(n)^2] = \min \quad (5)$$

Equations (6) through (8) define the Maximum Entropy Method.

The iterative procedure of Levinson recursion is applied to determine the prediction-error filter of order p:

$$\begin{bmatrix} 1 \\ a_{p,1} \\ a_{p,2} \\ \vdots \\ a_{p,p-1} \\ a_{p,p} \end{bmatrix} = \begin{bmatrix} 1 \\ a_{p-1,1} \\ a_{p-1,2} \\ \vdots \\ a_{p-1,p-1} \\ 0 \end{bmatrix} - \gamma_p \begin{bmatrix} 0 \\ a_{p-1,p-1} \\ a_{p-1,p-2} \\ \vdots \\ a_{p-1,1} \\ 1 \end{bmatrix} \quad (6)$$

The following lattice relationships are valid for n that falls in the range of $p \le n \le N-1$:

$$\begin{aligned} e_p^+(n) &= e_{p-1}^+(n) - \gamma_p e_{p-1}^-(n-1) \\ e_p^-(n) &= e_{p-1}^-(n-1) - \gamma_p e_{p-1}^+(n) \end{aligned} \quad (7)$$

The reflection coefficient, γ_p can be computed with the following equation:

$$\gamma_b = \frac{\sum_{n=p}^{N-1} [e_{p-1}^+(n) e_{p-1}^-(n-1)]}{\sum_{n=p}^{N-1} [e_{p-1}^+(n)^2 + e_{p-1}^-(n-1)^2]} \quad (8)$$

4. SIMULATION RESULTS

In order to verify the accuracy and effectiveness of the proposed tracking algorithm, several real-world image sequences containing moving vehicles and people were tested. The grayscale image sequences used were acquired using UNIQ-UP610 CCD camera and each image size is fixed to 256x256 pixels.

In our work, we have found that 2nd order Linear Prediction is sufficient to give good tracking results. The tracking system succeeds to track the detected moving object accurately in each sequence and is able to achieve real-time speed. Two of the image sequences are shown in Figure 3. Five of them (40 frames each) have been included for performance simulation analysis.

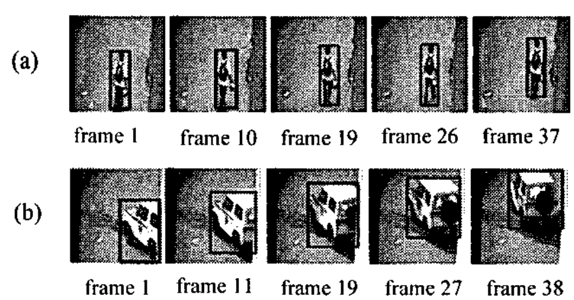

Figure 3: Tracking results by the proposed tracking algorithm.

The performance (in accuracy) of the proposed tracking method is shown in Figure 4 (taken from one of the 5 image sequences), which depicts the centroid locations (in pixel) of the tracked object obtained between using the 2nd order LP and Kalman Filter. The object for that sequence is moving from lower right to the top left portion. It can be seen that the accuracy of Kalman Filter degrades when the object maneuvers itself slightly near the top left portion of Figure 4, whereas Linear Prediction is able to track the object steadily.

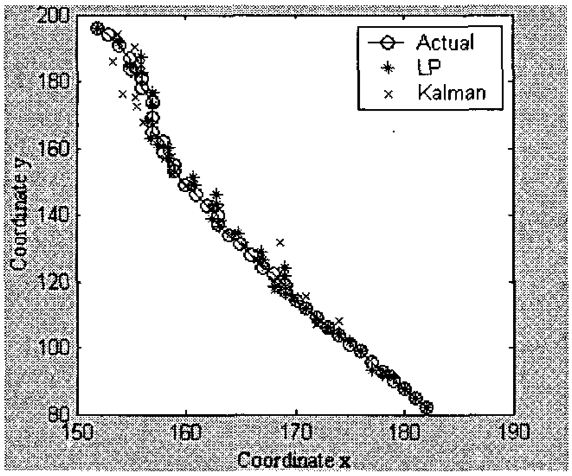

Figure 4: Accuracy comparison for the centroid locations of the target.

Comparison of the tracking accuracy (in terms of the average mean error) for each frame of the image sequences obtained between the proposed method and the Kalman Filter is depicted in Figure 5. It is clear that the proposed tracking algorithm exhibits better accuracy.

5. CONCLUSIONS

This paper has presented an alternative better tracking algorithm compared to the existing ones, by using conventional Linear Prediction technique. The algorithm predicts the centroid of the moving object which is based on the Projection Histograms technique. Prior to the Projection Histograms technique, motion detection based on the Hexagonal Edge Detector is employed. The results show a promising usage of the Linear Prediction technique for tracking of moving object.

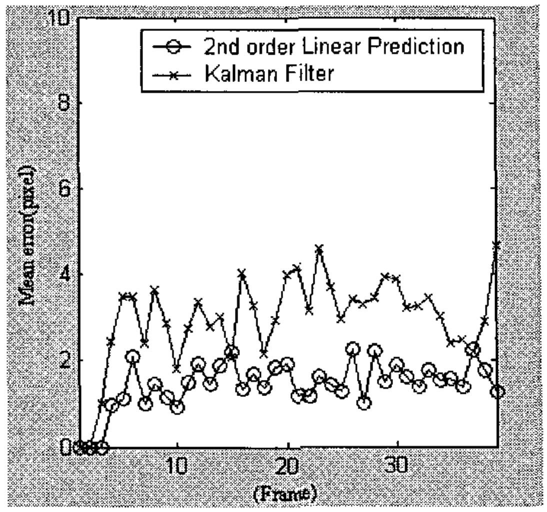

Figure 5: Average mean error vs each frame.

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